Surface ozone measurements at Taliarte, Gran Canaria (Canary Islands, Spain) (*)

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(ricevuto il 15 Marzo 1996; revisionato il 20 Settembre 1996; approvato l'11 Novembre 1996)

Summary. — From December 1990 tropospheric ozone concentrations have been measured at Taliarte station (Gran Canaria, Canary Islands). Taliarte's measurements are of great interest because of its proximity to Izaña BAPMoN observatory (Tenerife, Canary Islands) and its relative distance to high-pollution regions. A comparative study with other North-Atlantic stations has been carried out. In order to compare possible analogies and differences, a comparative study has been carried out. Studies involve seasonal cycle, diurnal oscillation and long-range transport. Ozone concentrations at Taliarte show high sensitivity to transport from higher latitudes. For diurnal variations, two different patterns have been found: "trade winds" and "marine breeze" situations.

PACS 92.60.Ry – Climatology.

1. – Introduction

The role of ozone is not only related to the high atmosphere, but also to the troposphere, where levels are considerably lower than in the stratosphere. Natural ozone concentrations in the troposphere are regulated by the chemistry which responds to natural emissions from biogenic sources and are influenced by the degree of the stratospheric input of ozone [1].

Ozone concentrations at middle and high latitudes of the northern hemisphere have been influenced significantly by photochemical production associated with emissions of NO_x, hydrocarbons, and CO from combustion of fossil fuels. Ozone over tropical continents may also be influenced by emissions from combustion [2]. Long-term measurements are sparse, even for Europe and North-America. Data for ozone are particularly lacking for the tropics and subtropics. Nevertheless, over the last few years some authors have reported measurements at remote sites describing ozone variations [3-5].

Ozone studies at locations far away from high-pollution centers have been carried out by Oltmans [6] for NOAA stations (Hawaii, Samoa, etc.) and by Oltmans and Levy II [7] for Bermuda and Barbados. Early ozone data from Izaña observatory have been

(*) The authors of this paper have agreed to not receive the proofs for correction.

studied by Schmitt *et al.* [8] and by Valero *et al.* [9]. In this context, the aim of this paper is to collaborate in the understanding of the behavior of tropospheric ozone at remote sites at subtropical latitudes.

2. – Experimental

Taliarte station (28° N, 16° W) is located on the east coast of Gran Canaria island (Canary Islands), 150 km away of the west african coast (fig. 1). The meteorological features of this region are dominated by the strength and position of the subtropical anticyclone (Azores' High), which is associated with persistent and strong winds, specially during summertime [10]. The northeastward movement of the anticyclone, sometimes as far as western Europe, gives rise to the arrival of air masses from the European continent or northwestern Africa, that could bring Saharian dust associated [11]. Sometimes the influence of a low-pressure system produces airflows of subtropical origin [12].

In December 1990, surface ozone measurements began at Taliarte. Some reasons move us to choose this location: its geographical situation at subtropical latitude, its relative distance from the high pollutants emission centers, and its proximity to Izaña BAPMoN station (80 km). Izaña is located 2370 m above sea level, while Taliarte is sited at sea level; this circumstance should be taken into account when examining their respective ozone levels. Moreover, during the last years the Atmosphere/Ocean Chemistry Experiment (AEROCE) has registered ozone levels and other air components at North Atlantic locations (Bermuda, Barbados and

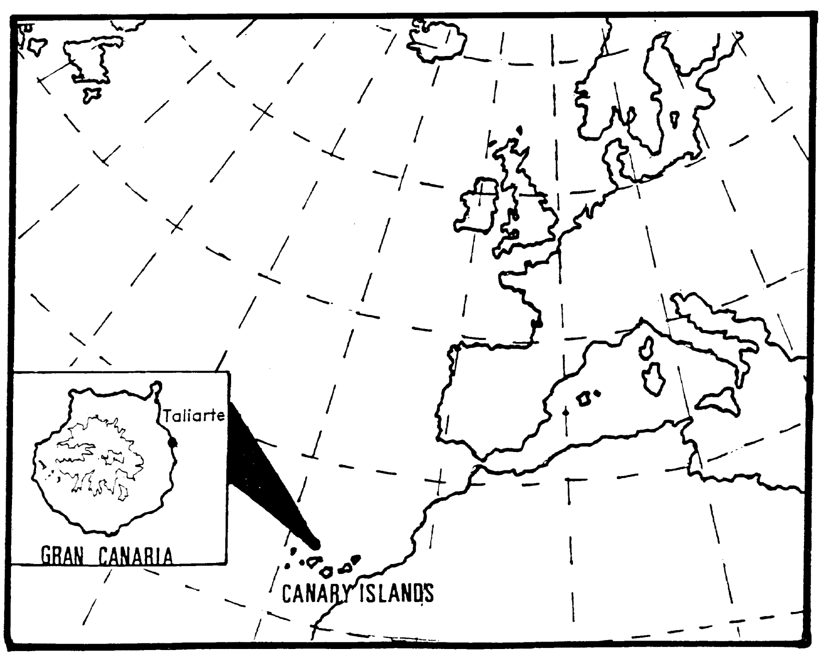

Fig. 1. – Location of Canary Islands and of Taliarte Observatory in Gran Canaria island.

Mace Head) to assess the contribution from the continents to the aerosols and gases in this region [13].

In this paper we use ozone series from Izaña, Bermuda and Barbados to compare ozone levels registered at Taliarte. Data from Izaña, supplied by INM (Instituto Nacional de Meteorología), belong to the period May 1987-December 1990. Bermuda series contain data from October 1988 to December 1990, and Barbados series from April 1989 to December 1990. Finally, data from Taliarte correspond to the period December 1990-August 1992. All the measurements are made using ultraviolet absorption instruments which have generally been found to produce reliable ozone data. The instruments at Taliarte have been intercalibrated with the spectrophotometer analyzer of Izaña. Moreover Izaña, Bermuda and Barbados have been intercompared with a network standard instrument maintained by the NOAA-Climate Monitoring and Diagnostic Laboratory (CMDL) in Boulder, Colorado [7]. Measurements at Taliarte were taken at 10 s intervals and averaged into hourly values. The zero-point calibrations were performed by scrubbing the ozone from an ambient air stream with activated charcoal and molecular sieve.

3. – Tropospheric ozone at North-Atlantic observatories

3·1. *Statistical features.* – As a previous analysis for the description of O_3 variations registered at Taliarte station, we compared the statistical characteristics of ozone data registered in the four North Atlantic observatories. Statistical summaries are presented in table I.

Taliarte ozone concentrations (fig. 2) show a nearly normal distribution of data, although for values in the range between 5 and 15 ppb their frequencies are higher than those that would be expected for a normal distribution. This may be attributed to persistent low values during December 1990 and early January 1991. O_3 concentrations registered at Izaña (fig. 3) have their maximum frequencies between 30 and 50 ppb showing a relative bias to high concentrations. The difference with the values registered at Taliarte may be due to the different altitude of the two canary observatories. Moreover, Izaña is normally above the trade wind inversion, while Taliarte is below [14]; this feature involves differences between the air masses arriving at each station. The shape of Bermuda O_3 histogram (fig. 4) is quite different from the one previously described, here we observe a bimodal distribution of data, with higher frequencies for 17.5 and 33.5 ppb, and a relative dispersion of data around 60-80 ppb. Finally, ozone concentrations at Barbados (fig. 5) show a frequency distribution biased to low values with 40% of total around 17.5 ppb.

In order to get more information from ozone distribution, we have compared the histograms with the corresponding wind distribution by sectors (obtained from climatological data). The distribution frequencies by sectors in Barbados have nearly

TABLE I.

	Taliarte	Izaña	Bermuda	Barbados
Mean	30.59	43.03	32.63	20.43
Standard deviation	10.09	10.05	13.74	5.62
Median	30.69	41.29	33.40	19.50

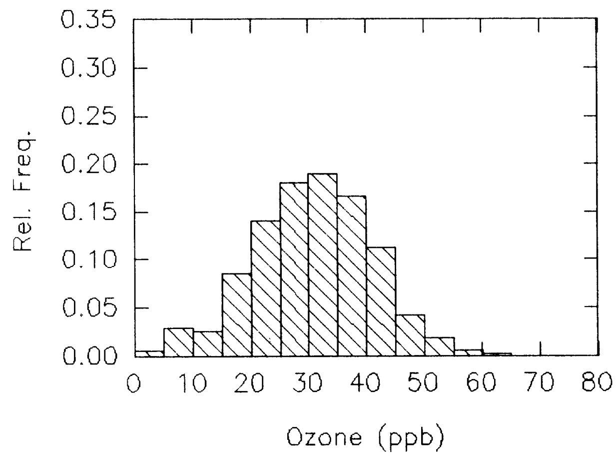

Fig. 2. – Distribution of frequencies of ozone concentrations at Taliarte.

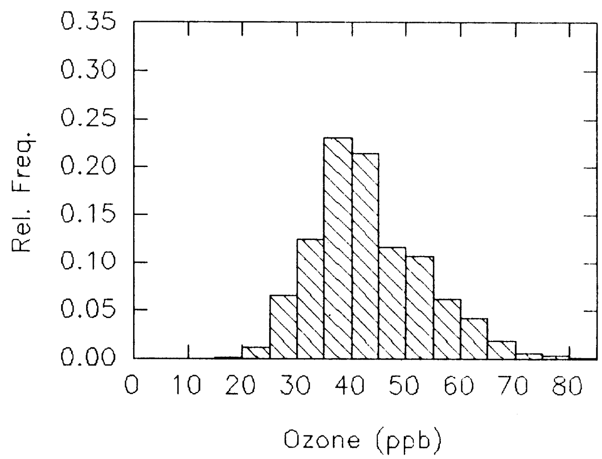

Fig. 3. – Distribution of frequencies of ozone concentrations at Izaña.

90% of winds coming from East; this direction is associated with trade winds, whose persistence could be related to O_3 distribution. Wind distribution at Taliarte presents similar characteristics, where higher frequencies are associated to North direction. Anyway, this distribution is seriously affected by the orography of the island, deviating trade winds to NNE, and intensifying their strength. Valero *et al.* [9], have found that concentrations of ozone at Izaña are influenced by air masses origin. Air masses coming from North Atlantic sector are associated with high O_3 concentrations at Canary Islands; the lowest concentrations were found associated to air masses coming from tropical area.

Wind direction distribution at Bermuda seems to be in good agreement with O_3 concentrations. The main wind directions are from S-SW (34%) and W-NW (28%); these

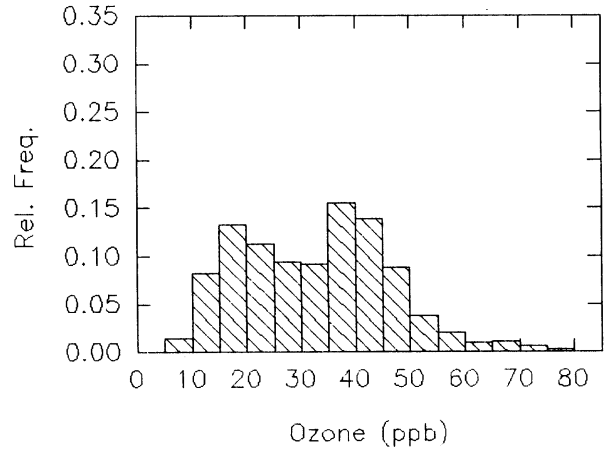

Fig. 4. – Distribution of frequencies of ozone concentrations at Bermuda.

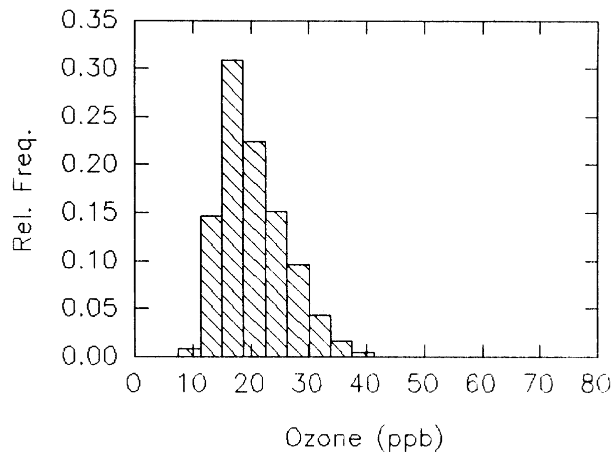

Fig. 5. – Distribution of frequencies of ozone concentrations at Barbados.

directions could explain ozone bimodality. High O_3 concentrations are associated with flows from the midtroposphere over North-America. Nevertheless, some instances of ozone pollution transported from North-America have been reported [15, 7]. On the other hand, air masses coming from S-SW could explain the 17.5 ppb peak observed in ozone distribution.

3'2. *Seasonal variation.* – Figure 6 shows seasonal variation at Bermuda, Barbados, Izaña and Taliarte. In this figure we can see that Taliarte and Bermuda show almost the same seasonal variation; besides, lower values at Taliarte than at Bermuda during winter and higher during summertime are observed. Spring maximum at Taliarte is delayed with respect to Bermuda, this feature and a higher

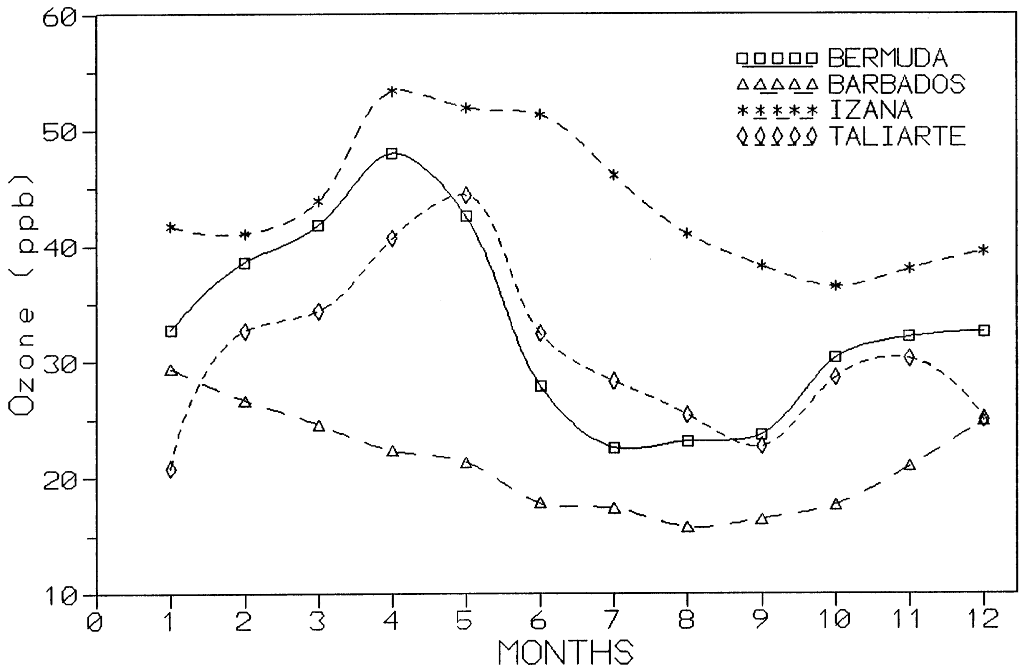

Fig. 6. – Seasonal variation of ozone at North-Atlantic observatories.

mean value at Bermuda than at Taliarte could be related to tropospheric ozone latitudinal gradient [2].

The main difference of these measurements with respect to Izaña, involves mean values. Higher values at Izaña are related to altitude. Moreover, one can observe a more spread spring maximum at Izaña associated with inter-annual variability; spring maximum does not appear in the same month year by year (we work with a more extended period of study in this station).

The annual amplitude at Taliarte oscillates around 20 ppb, while at Izaña the amplitude takes values around 15 ppb, due to a bigger monthly dispersion of data at Taliarte than at Izaña. Monthly minimum values at Taliarte were registered in September, when trade winds have their lowest frequency. During winter, we have observed frequent oscillations in ozone concentrations at Taliarte, associated to the occurrence of different synoptical patterns affecting Canary Islands. This behavior is not so obvious at Izaña. In June, at Taliarte, we have significant monthly dispersion too, probably associated with the cease of stratospheric influx.

At Barbados, seasonal variation is quite different from the others'. In this observatory we do not find spring maximum; the highest values are reached during winter. Oltmans and Levy II [7] attribute seasonal maximum at Barbados to transport from higher latitudes and altitudes. Of particular interest over ozone concentrations at Barbados is the potential impact of biomass burning in Africa [16]. In fact, during summer and autumn months, the relatively low ozone concentrations are associated with the transport from Africa.

4. – Tropospheric ozone at Taliarte observatory

4˙1. *Diurnal variation.* – Ozone diurnal variation at Taliarte is strongly influenced by two different situations, dominating trade winds and marine breeze. Figure 7 shows the average most frequent diurnal variation under marine breeze conditions (this situation is characterized by low wind speed). A relative nocturnal maximum is found around 4 a.m., then, ozone concentration decreases from 7 to 9 a.m. A more spread maximum that persists from 12 a.m. to sunset is found too.

Nocturnal maximum may be caused by ozone transport coupled to breeze from inside the island to the coast [17]. Diurnal maximum is associated probably with favorable general atmospheric situation (low wind speed and clear skies), that could help photochemical ozone production *in situ*.

Under trade winds predominance (characterized by high wind speed), the shape of diurnal variation curve is very different from the one described above. In this case (fig. 8), we have registered nearly constant ozone concentrations along the day, with values around 30 ppb. According to this result, one can think that trade winds situation is not related with photochemical processes.

These different patterns are present in monthly mean day more or less, depending on the frequency of each one. So, we have observed that during months when trade winds are not dominant (autumn and winter) the diurnal evolution curve is similar to the breeze situation (fig. 7), while during summertime the curve shape is nearly the same as in the trade winds case. During springtime, trade winds are not as persistent as during summertime; this circumstance is patent in diurnal variations, with similar behavior to breeze situation, although its amplitude is not so big as during autumn and winter.

Figure 9 shows diurnal variation at Taliarte for the whole period of study. This figure is similar to the one described for springtime, with oscillations around a mean value (30 ppb). This indicates that although the trade winds situation is the most frequent one, days with high oscillation of ozone concentrations have important effects

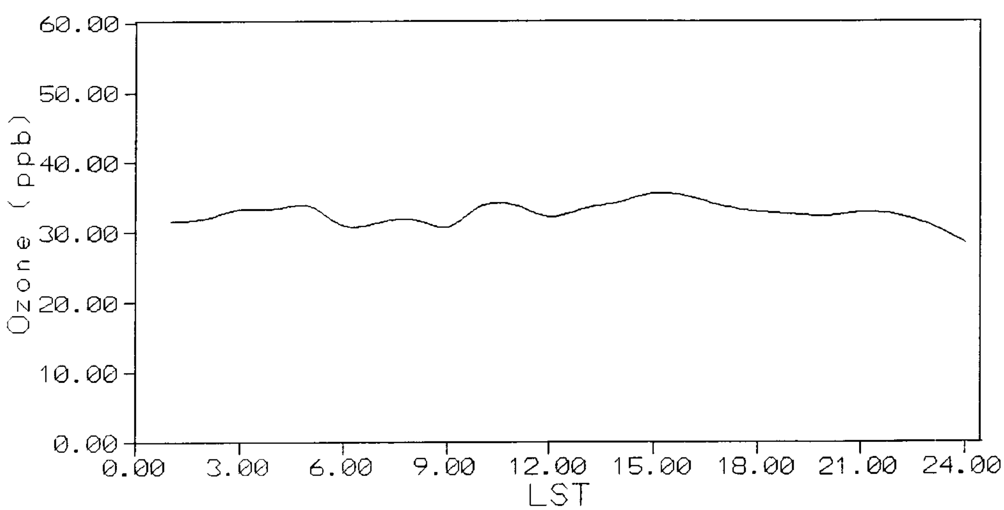

Fig. 7. – Diurnal variation under breeze situation.

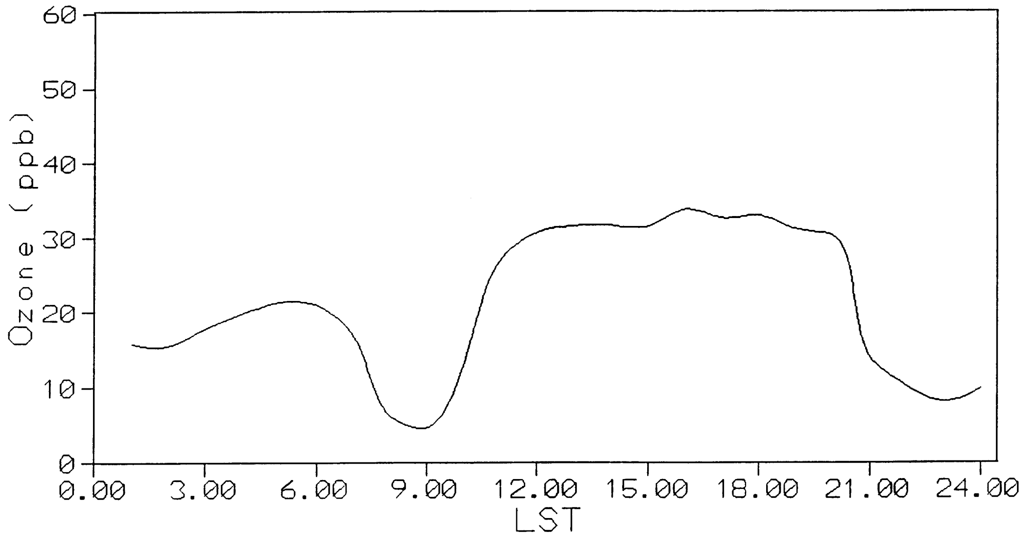

Fig. 8. – Diurnal variation under trade winds situation.

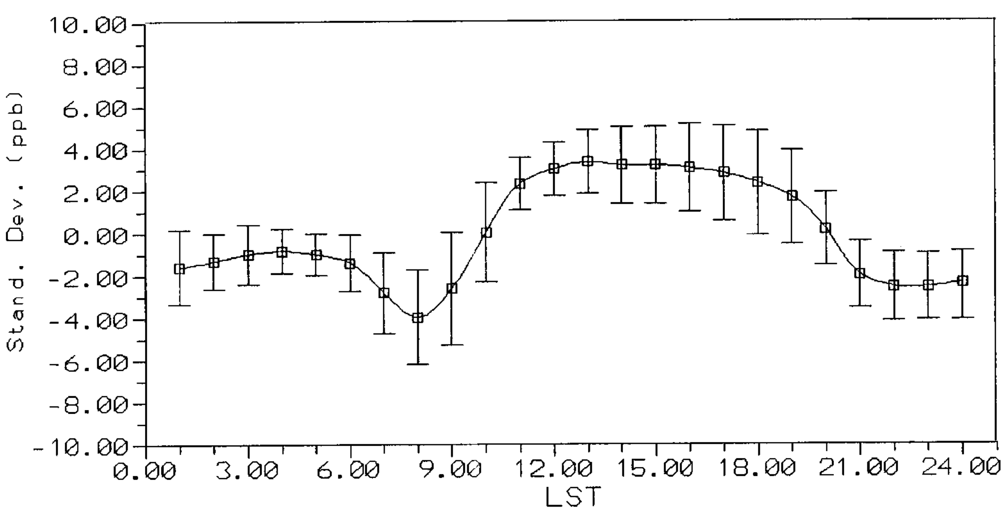

Fig. 9. – Mean diurnal variation of ozone in Taliarte.

over mean diurnal cycle. Daily variations at Taliarte represents 20% of the annual mean concentrations and 30% of the seasonal variation.

4·2. *Case studies of ozone-pressure correlation events.* – To assess the relationship between ozone concentrations and wind origin described in this paper, we present ozone evolution during December 1990-January 1991, June-August 1991, and their corresponding pressure fields. In both cases pressure oscillations are reflected in good agreement with ozone registered at the station (fig. 10). In general, high pressure is

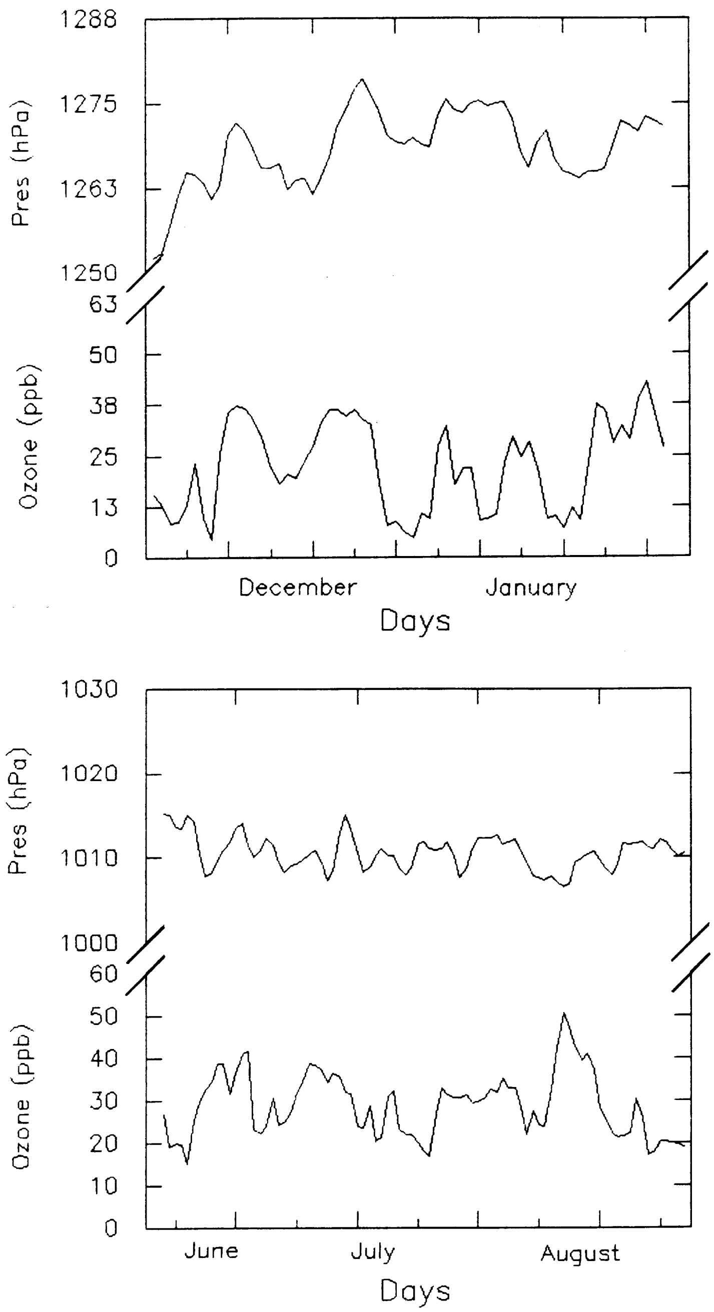

Fig. 10. – Daily evolution of ozone and pressure in Taliarte during the periods of study.

associated with high ozone concentrations, while ozone low values are related to pressure decline. Synoptic patterns corresponding to high ozone concentrations present a spread anticyclonic system (Azores' high) over the Atlantic ocean (typical

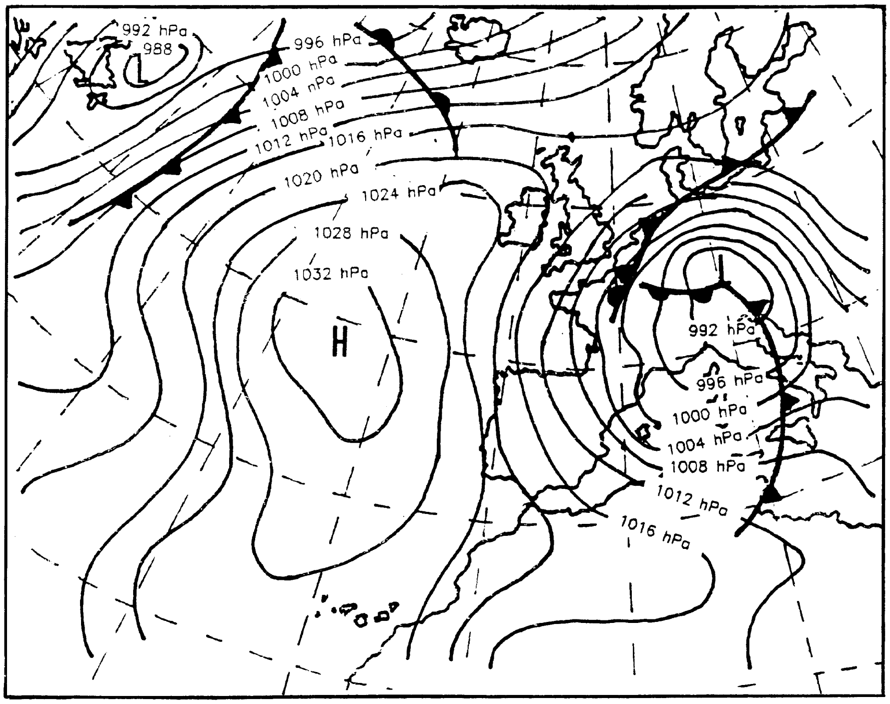

Fig. 11. – Synoptic pattern during December 10-13.

situation for the predominance of trade winds). However, low ozone concentrations are associated with synoptic patterns that involve air coming from Sahara, from lower latitudes, or local winds. These meteorological features indicate a high-latitude source for high ozone concentrations and a decrease of ozone when transport of air from higher latitudes is restricted.

December 1990-January 1991. From December 10 to 13, 1990 (fig. 11), the synoptic pattern is characterized by a meridionally extended Atlantic anticyclone that makes it possible for marine polar high speed air masses to arrive at Canary Islands. Ozone concentrations reach 30 ppb and the diurnal oscillation is quite similar to the above described (fig. 8). Similar ozone concentrations and diurnal cycle have been observed from December 21 to 27. Nevertheless, the synoptical pattern differs a little from the previous one. Here, the Atlantic anticyclone is located at more meridian latitudes; midlatitude marine flows arrive at Canaries under this meteorological feature (fig. 12).

Conversely to those situations, from December 29 to January 4, and from January 19 to 23, 1991, flows from higher latitude cease and ozone levels decrease to 15 ppb, and the diurnal cycle observed becomes similar to that of fig. 7. The synoptical pattern during these periods (fig. 13) shows a spread anticyclone over Europe whose axis is oriented from West Europe to the Atlantic Ocean. This pattern, commonly

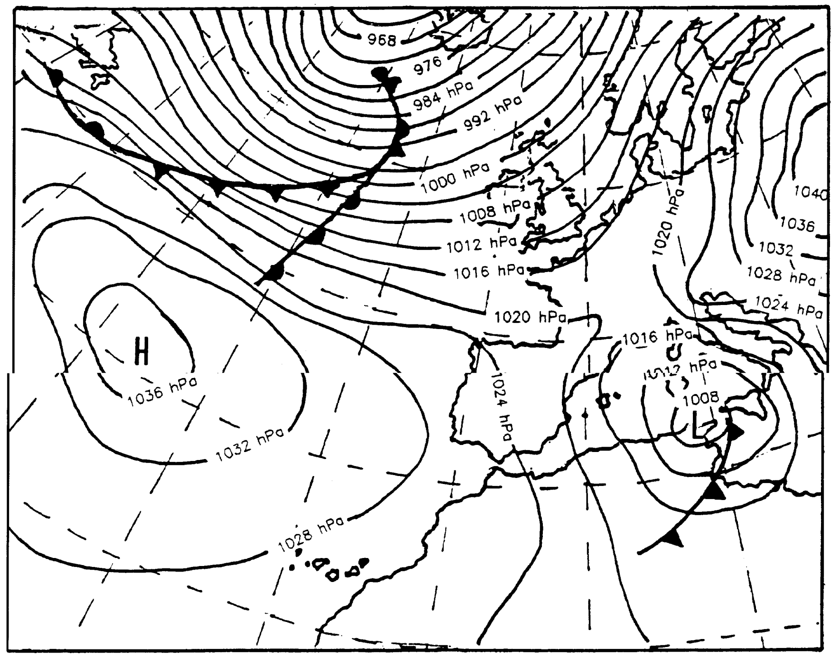

Fig. 12. – Synoptic pattern during December 21-27.

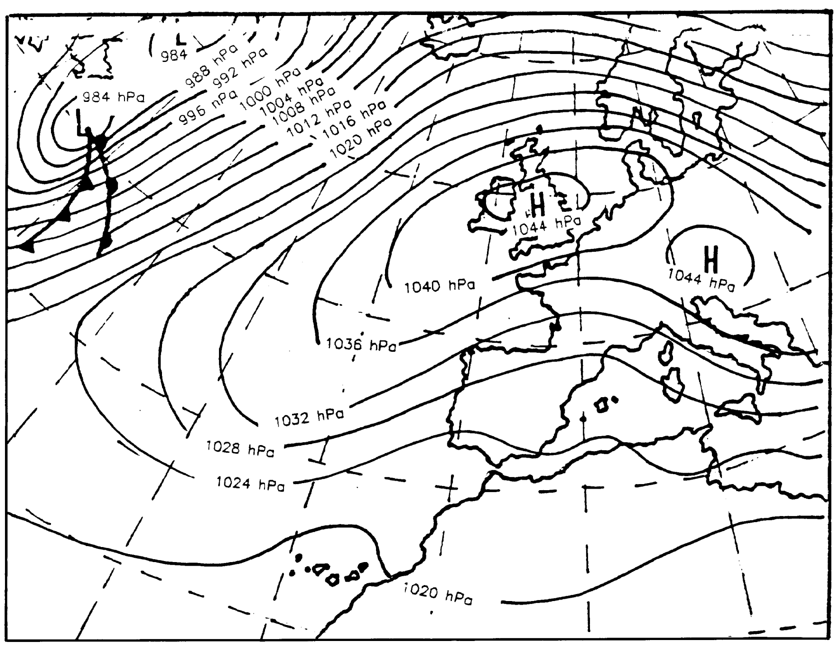

Fig. 13. – Synoptic pattern during December 29-January 4 and January 19-23.

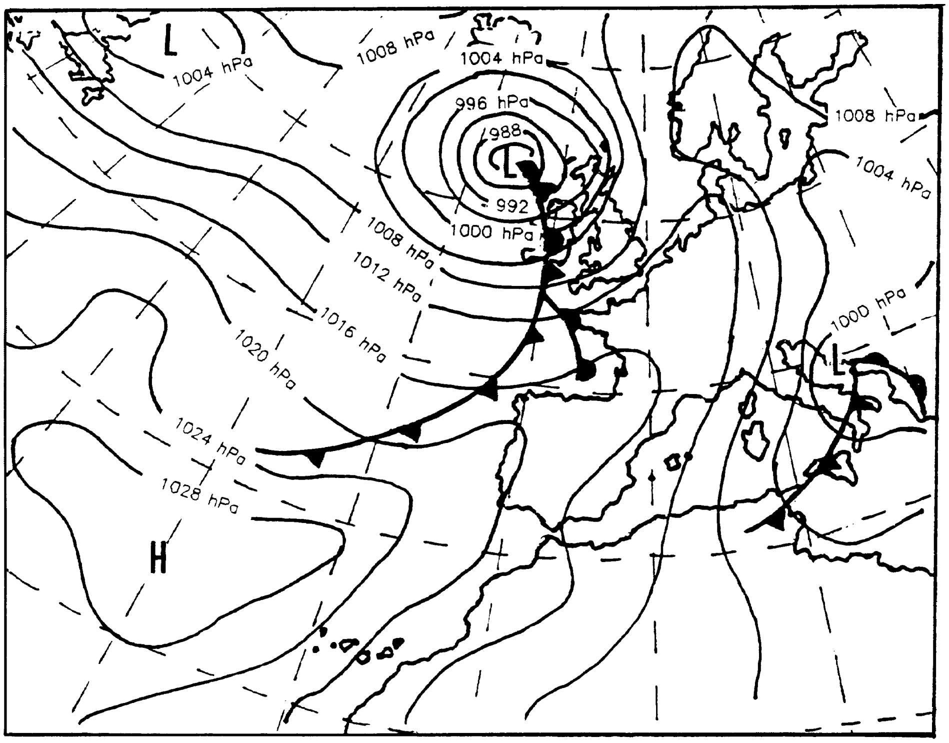

Fig. 14. – Synoptic pattern during June 7-10.

known as East waves [18], has flows associated from Sahara desert. Low ozone concentrations during these periods are in good agreement with uniformly low ozone levels at Barbados during periods of enhanced transport from Africa [19].

June-August 1991. During summertime, trade winds reach their greatest persistence, with relative frequencies around 75%. This situation is only disturbed by flows coming from the Sahara desert. The climatological characteristic of this season has an important influence over the ozone diurnal cycle, with high and nearly constant concentrations (fig. 8). Nevertheless, an important difference in mean ozone concentrations when flows have continental or marine origin has been observed.

From 7 to 10 June, ozone concentrations registered in Taliarte were around 25 ppb. Meteorological patterns during these days show the Atlantic high situated in the west side of Canaries (fig. 14), so maritime air masses can be expected under this situation. From 10 to 15 August ozone concentrations reached the highest values of the summer (45 ppb). A low-pressure system over the Sahara desert is observed in the synoptic pattern (fig. 15); this pressure field allows air masses with origin in Morocco or mediterranean latitudes to arrive at Canary Islands. The changes in ozone mean levels in these periods may be attributed to the different chemical composition of the associated air masses. Presumably, the last ones are richer in ozone, due to accumulation effect during winter, [20] than those of oceanic origin.

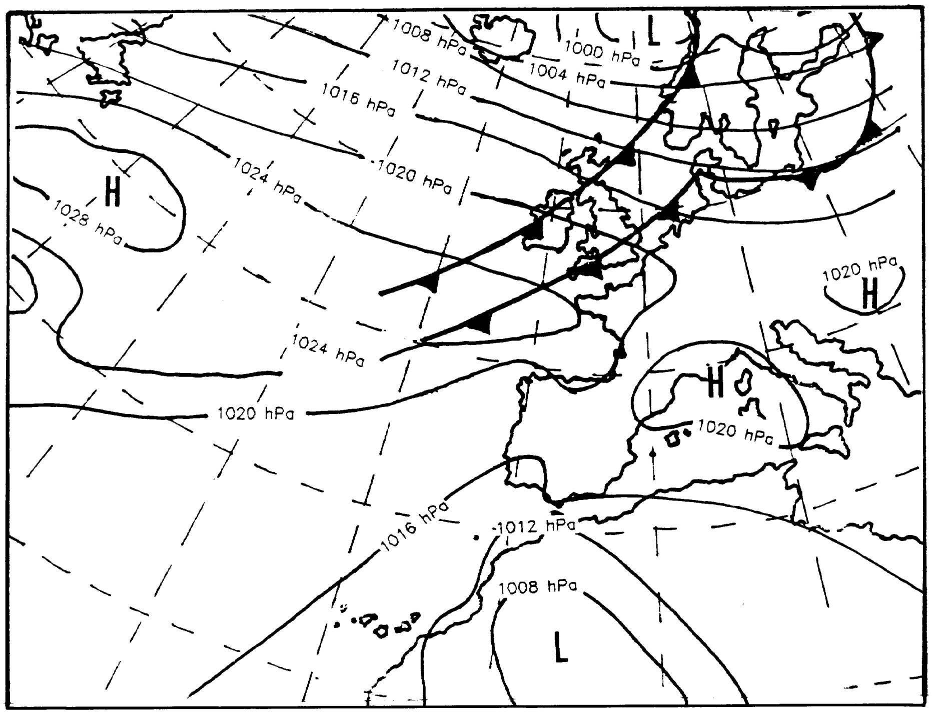

Fig. 15. – Synoptic pattern during August 10-15.

5. – Summary and conclusions

As a contribution to the understanding of the behavior of tropospheric ozone in subtropical latitudes, Taliarte station began to measure ozone concentrations in December 1990. In order to improve the accuracy of Taliarte's levels, stations at similar latitude (Bermuda, Barbados, and Izaña) have been used to test them. Non-contemporary data were forcedly used because at the time of developing this paper contemporary data were not available; anyway, due to the statistical stability of this sort of data, we expect the results not to be, in our opinion, different from those obtained herein. Seasonal variation at Taliarte shows reliable analogies with Bermuda and Izaña. A relation between the shape of ozone frequencies distribution and wind distribution by sectors has been observed. Related to this feature, two typical diurnal cycles have been found, "trade winds situation", with nearly constant ozone concentrations along the day, and "marine breeze situation", characterized by higher oscillations along the day.

Finally, Taliarte's ozone concentration shows high sensitivity to long-range transport from higher latitudes; this feature has been observed during two different periods. The meteorological synoptic pattern elucidates that high ozone concentrations are associated with meridian flows, while low ozone levels are registered when transport from higher latitudes is restricted.

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The authors wish to thank CMDL-NOAA for its support and data supplied, and the Spanish Institute of Meteorology (INM) for the data from Izaña, and specially Centro Insular de Tecnología Pesquera de Taliarte (Gran Canaria) where the instruments of the analysis are installed.

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